# PROPULSION DIRECTORATE

## Monthly Accomplishment Report
## January 2001

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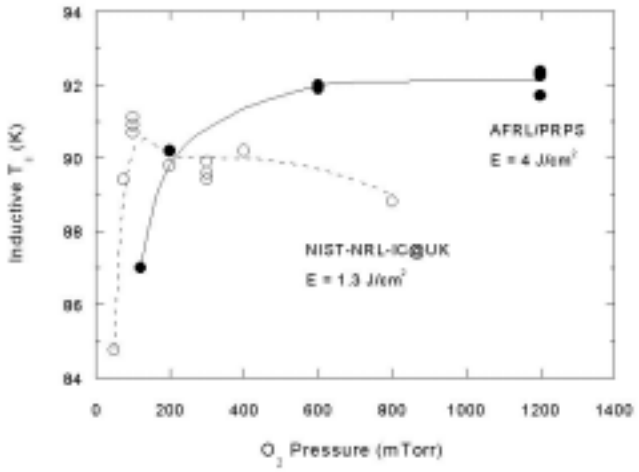
PLANNING BEGINS FOR HIGH CYCLE FATIGUE MODEL VALIDATION DEMONSTRATOR: Planning has begun for the Pratt & Whitney (P&W) Integrated High Performance Turbine Engine Technology (IHPTET) High Cycle Fatigue (HCF) Model Validation Demonstrator Engine. Also known as the XTE 67/SE1, this production configuration F119 engine, provided by the F119 Program Office, will be delivered to the IHPTET Program for extensive instrumentation and HCF engine testing. Production number P730037 will be delivered in late summer 2001 and will then undergo a nine-month instrumentation process. During this procedure, the engine will be outfitted with the latest instrumentation such as an Inlet Debris Monitoring System, Advanced Non-Intrusive Measurement System, High Fuel/Air Ratio Probes, Thermographic Phosphors, crack detection sensors, and an Engine Distress Monitoring System. Testing is scheduled for the summer of 2002 at Arnold Engineering and Development Center. Although the testing is specifically designed to validate the IHPTET HCF prediction/design codes and test protocols, it will also supply the F-22 System Program Office with a fully characterized baseline/production F119 engine as well as provide a first look at how well the engine will combat HCF in the field. After the test program has been completed, there is a potential for the engine to continue its service as a technology demonstrator. If future builds of this engine can include more IHPTET technologies, technology transition to the F119 engine will be accelerated. (Capt A. Cerminaro, AFRL/PRTP, (937) 255-2767)

F119 engine

F-22 Raptor

NEW PULSED LASER DEPOSITION SYSTEM PRODUCES RESULTS: A new pulsed laser deposition (PLD) facility for superconducting YBCO (yttrium barium copper oxide) has recently been brought on-line in the Propulsion Directorate (AFRL/PRPS). The purpose of the new system is to create YBCO samples for use in flux pinning experiments. This system, which alleviates a production bottleneck caused by another PLD facility being down for an extended period, is already producing meaningful results. The critical temperature ($T_c$) of the PRPS-created YBCO (measured by magnetic susceptibility) is generally 92 K, which is higher than other reported $T_c$s that are at most 90-91 K. Deposition results based on varying oxygen ($O_2$) partial pressures during ablation of the YBCO were compared to other published results, and the results indicated a difference in that a maximum benefit to varying the $O_2$ partial pressure was found. One speculated possibility is that the melting point of YBCO increases as $O_2$ partial pressure is increased, thus an increase in substrate temperature (or plume energy) will obtain

YBCO film crystallinity at higher $O_2$ pressures. Future flux pinning experiments will incorporate various REBCO (rare earth barium copper oxides) in the YBCO as well as phase variation additions. Pinning the flux will improve the current density and ac loss properties of the YBCO conductor. YBCO coated conductor is being developed for high temperature superconducting (HTS) applications. (P. Barnes, AFRL/PRPS, (937) 255-2923)



YBCO Critical Temperature Measurement vs. Partial $O_2$ Pressure


YBCO deposition rig

POSS INHIBITOR DEVELOPED UNDER GREEN MISSILE PROGRAM: The Propulsion Directorate's Polymer Working Group (PWG) has successfully completed their efforts on the Green Missile Program. The main goals of the Strategic Environmental Research and Development Program (SERDP) Green Missile Program were threefold: (1) develop lead-free extrudable and castable propellant for minimum smoke systems, (2) develop complete and clean, HCl-free, combustion of propellants, and (3) develop solventless methods for processing energetic oxidizers. The task of the PWG was to select, synthesize, characterize, scale-up, and process a new POSS (polyhedral oligomeric silsesquioxanes) inhibitor to work with new thermoplastic elastomeric propellants for tactical missiles. The three-year program resulted in the successful development of a new inhibitor that adhered extremely well to both poly-BAMO/AMMO and Hytrel-based inhibitors. The PWG was able to extrude the new inhibitor (POSS-polynorbornylene), which could result in tremendous process cost-savings. At the conclusion of the program, the inhibitor was sent to Naval Surface Warfare Center


POSS inhibitor being wrapped around propellant

- Indian Head for wrapping around live firing and subsequent firing. Further developmental work may be undertaken based on the success of this program. (S. Phillips, AFRL/PRSM, (661) 275-5416)

EDWARDS HONORED BY JANNAF: The Joint Army-Navy-NASA-Air Force (JANNAF) Airbreathing Propulsion Subcommittee (APS) recently honored Dr. J. Timothy Edwards of the Propulsion Directorate. The JANNAF APS is concerned with ram-compression airbreathing propulsion systems over the entire range of atmospheric propulsion for rocket and missile applications. Systems covered by the subcommittee include solid- and liquid-fueled ramjets, ducted rockets, expendable turbojets, supersonic/hypersonic aerospace planes, missile engines, and combined-cycle engines oriented towards space and missile applications. Dr. Edwards received one of the two annual JANNAF APS Awards given in 2000 for his lasting technical contributions in the areas of fuels and thermal management. Dr. Edwards currently serves as the Technology Manager for the Propulsion Directorate's Fuels Branch (AFRL/PRTG). This award was presented to Dr. Edwards (*in absentia*) on 14 November 2000 at the JANNAF Joint Subcommittee Meeting in Monterey, California. (W. Harrison, AFRL/PRTG, (937) 255-6601)


Dr. J. Timothy Edwards

*Want more information?*

- Dr. Edwards is recognized on page 10 of the January 2001 CPIA Bulletin available online at http://www.cpia.jhu.edu/Bulletin/PDFFiles/jan01bulletin.pdf.

ADVANCED TURBINE ROTOR CLEARED FOR TEST: Pratt and Whitney has successfully completed spin pit testing of the Twin Web Disk (TWD) turbine rotor for the initial demonstration of the Integrated High Performance Turbine Engine Technology (IHPTET) Phase III Advanced Turbine Engine Gas Generator (ATEGG). Benefits of the TWD concept include a significantly higher $AN^2$ capability (+37 percent) than a conventional turbine rotor and reduced weight. The high $AN^2$ capability of the TWD concept is vital for the achievement of the IHPTET Phase III goals. The initial spin pit verification of the TWD was aborted at 91 percent of the operational speed due to an indication of asymmetric yielding in the aft bore. It was determined that


Twin Web Disk turbine rotor

thermal gradients present in the full-scale rotor during heat treatment resulted in significant residual stress in the aft bore. Forging heat treatment procedures for future twin web disk rotors will be modified to avoid this problem. Analysis of the full-scale rotor concluded that it has enough margin to successfully operate in the ATEGG testing. The rotor was reinstrumented and balanced for a final proof test to clear the rotor to provide a 10 percent minimum burst margin for the core tests. The rotor reached 100 percent of the goal speed, which will allow the ATEGG core and engine to run with minimal structural or acceleration restrictions. The first build of the ATEGG core is scheduled to begin testing in May 2001 at the Arnold Engineering and Development Center. This core is expected to contribute to the demonstration of a 70 percent improvement in thrust to weight. (D. Jay, AFRL/PRTP, (937) 255-2278)

NEW BUFFER PROCESS FOR HIGH TEMPERATURE SUPERCONDUCTORS: Under a Ballistic Missile Defense Organization (BMDO) SBIR managed by the Propulsion Directorate, Applied Thin Films, Inc (ATFI) has developed an innovative process for applying Yttria-Stabilized Zirconia (YSZ) buffers to the metal substrate of YBCO (yttrium barium copper oxide) coated conductors. YBCO coated conductors are being developed for high temperature superconducting (HTS) applications. ATFI has worked with the Power Systems Branch (AFRL/PRPS) to develop this proprietary process. In YBCO coated conductors, a metallic substrate is typically used upon which subsequent layers are deposited. These layers consist of initial buffer oxide layers and then the superconducting YBCO itself. Although YSZ is a commonly used buffer layer, the process created by ATFI and currently being developed with the Air Force applies the YSZ buffer much more rapidly than typical processes which allows a reduction in processing time and cost. This breakthrough process has the potential to eventually become the standard method for applying buffers to the substrate. (P. Barnes, AFRL/PRPS, (937) 255-2923)

STUDY OF REUSABLE LAUNCH CONCEPT INITIATED: The Propulsion Directorate's Applications and Assessments Branch (AFRL/PRST) has initiated a system study to explore a potential near-term concept that would be capable of placing approximately 50 kg in low Earth orbit. This task is being conducted at the request of DARPA/TTO. The vehicle concept (referred to as RASCAL) employs a pre-cooled turbojet with liquid air injection for a reusable first stage. The upper two stages are propelled by expendable hybrid rocket motors. A Propulsion Directorate interdivisional analysis team will define the engine

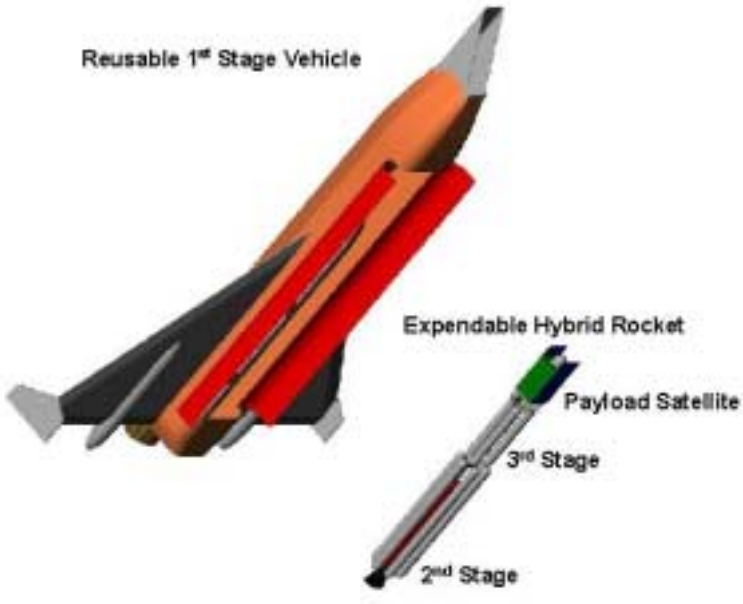


Illustration of RASCAL launch vehicle elements

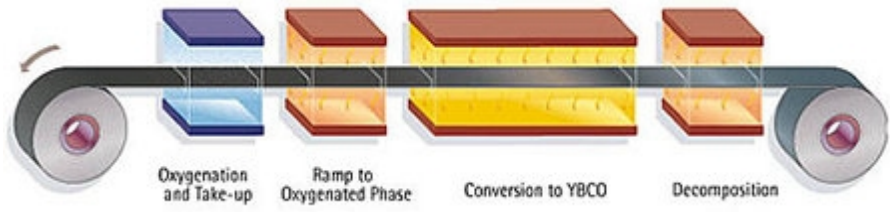
performance and vehicle mass properties. A complete mission simulation will be computed, including ascent trajectory and booster recovery. DARPA has identified a potential market within the Air Force for such a small-scale reusable launch system. (R. Moszee, AFRL/PRST, (661) 275- 5534)

U-2 COLD FLOW PROGRAM RECEIVES FAVORABLE REVIEW: During recent high-level program reviews for the U-2 reconnaissance aircraft, the Propulsion Directorate's program to develop a new low-temperature fuel received very favorable marks. The U-2 Senior Year Executive Review was held during the week of 4 December 2000. This review is a meeting between top management of the U-2 Directorate at Warner Robins Air Logistics Center (WR-ALC), the 12th Air Force (operators of the U-2), and the Reconnaissance SPO (ASC/RA). During this meeting, all programs associated with the U-2 were reviewed, including the program to develop a new low-temperature fuel dubbed JP-8+100 LT (LT for *low temperature*). This program received a very favorable review, and additional funds were offered to accelerate the program. However, the additional funding was declined because it is believed that acceleration of the program at this time would add unwarranted risk. The development of JP-8+100 LT stems from a desire to replace JPTS, the fuel used for the U-2, with the more economical JP-8. It is estimated that replacing JPTS with JP-8+100 LT will save the Air Force an estimated $8.2 million per year in fuel costs. Research in this area has been very productive to date, and a new cold flow fuel system simulator was activated in November 2000 to support these research efforts. (C. Obringer, AFRL/PRTG, (937) 255-6390)


U-2 reconnaissance aircraft


A portion of the cold flow fuel system simulator

DUAL-USE PROGRAMS FOR YBCO COATED CONDUCTORS: Two dual-use programs were recently awarded under the Propulsion Directorate's topic, "High Temperature Superconducting (HTS) Coated Conductors for Power Generation and Magnets" (01-PR-05). The goal of this topic is to develop an effective approach in manufacturing long lengths of HTS coated conductor that can be wound in coils for power generators. One program has been awarded to American Superconductor Corp (ASC) for fabrication of YBCO (yttrium barium copper oxide) conductor using the rolling assisted bi-axial textured substrate (RABiTS) approach. The other program was awarded to IGC SuperPower, LLC to use ion beam assisted deposition (IBAD). Air Force funds for ASC and IGC SuperPower are being provided jointly by the Propulsion and Materials Directorates. The RABiTS approach has the potential to become the more economical process, while IBAD has

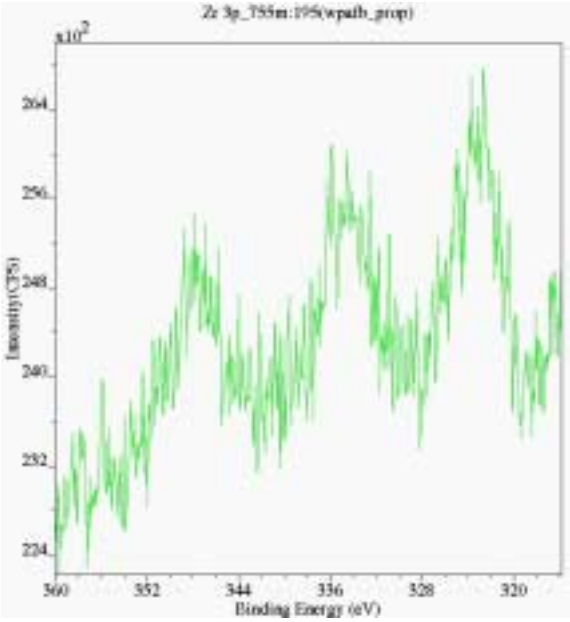


American Superconductor Corp's YBCO deposition process

demonstrated better quality conductor and is further along the development path. The combined programs including Air Force, DUST, and industrial funding total nearly $4.5 million over three years. The production of viable YBCO coated conductor offers a reduction in HTS conductor cost from $300 per kA-m for present day BSCCO to almost $10 per kA-m. The YBCO conductor can also carry engineering current densities the same as or slightly greater than BSCCO conductor, but at liquid nitrogen temperatures (77 K) as opposed to 20-30 K for the first generation BSSCO. The conductor is needed for multi-megawatt generators to provide power to electrically-driven directed energy weapons currently in development. (P. Barnes, AFRL/PRPS, (937) 255-2923)

ACTIVITIES IN ENGINE HEALTH MONITORING (EHM)**:** Impact Technologies is to field an engine test cell diagnostic system capable of statistical anomaly detection of engine sensor signals, mechanical and performance-based diagnostics, and vibration image fault detection and isolation. This advanced test cell diagnostic system will perform both real-time and post-test diagnostic assessments of engine performance and mechanical faults so engine anomalies can be identified promptly and associated maintenance prioritized. Payoffs from this effort will be in the form of reduced testing, increased availability, and sizable cost reductions. A suite of AI technologies will be integrated with engine test cell control and monitoring software to provide real-time diagnostics and prognostics for the test cell environment. The developed system will use hyperspectral imagery to provide statistical anomaly detection of engine sensor signals, mechanical and performance-based diagnostics, and vibration image fault detection and isolation. The system will initially be installed and tested on an F404 test cell at the Jacksonville NAS to better support the F414 upgrade for next year. This will provide the benchmark test for passing engines off into service and allow for the accurate evaluation of performance over time. The benchmark test is crucial in trending and for the accurate diagnosis of engine failures and faults. Several other government and commercial organizations are very interested in this test cell upgrade capability. Immediate payoffs from this effort will be in the form of an approximately 25 percent reduction in turnaround time at engine depot test cells. Based on a heavily used test cell (50 engines per year), this reduced time will result in savings of $750k to $1M annually. Air Force research into EHM is growing to offer the best tools to improve engine availability at the lowest manpower effort and cost. EHM will make engines more affordable and is the key to the Intelligent Engine in VAATE. (W. Sotomayer, AFRL/PRTC, (937) 255-1684 and Sqn Ldr R. Friend, AFRL/PRTC, (937) 255-2734)

SUPERCONDUCTIVITY GROUP DISCOVERS Zr DIFFUSION IN YBCO LAYER: Dr. Sharmila Mukopadhyay of Wright State University collaboratively supported Propulsion Directorate (AFRL/PRPS) studies of high temperature superconducting (HTS) coated conductors under the directorate's Summer Faculty Program. Dr. Mukopadhyay used a unique, high resolution X-Ray Photoelectron Spectroscopy (XPS) system to examine an HTS coated conductor sample. This detailed study of the sample revealed inter-diffusion of material in the coated conductor as well as a possible difference in chemical states of the yttria. The yttrium (Y) photo-electronic peak shape in the coated conductor films is very different from bulk YBCO (yttrium barium copper oxide) superconductors studied previously using XPS and discussed in existing references. A difference in XPS peak shape might indicate some difference in the atomic coordination between laser-ablated and bulk-sintered films. Furthermore, the lower part (bottom 2/3) of the YBCO film showed distinct signs of contamination, perhaps from diffusion through buffer layers. Definite traces of nickel were seen, but the peaks were not strong enough to be quantified. However, quantifiable zirconium (Zr) and cerium (Ce) signals were detected in the YBCO. Measured Zr and Ce signals (averaged over 1/3-2/3 region of entire film) gave a Zr/Y ratio about 10 percent and a Ce/Y ratio of about 3-5 percent. The Ce concentration increased slowly while sputtering deeper and deeper into the YBCO (indicating approach to or past the $YBCO/CeO_2$ interface), but the Zr concentration remained nearly steady inside the YBCO part of the specimen clearly prior to the YSZ (yttria-stabilized zirconia) interface. HTS coated conductors are important for the development of compact coil windings and magnets needed for such applications as directed energy weapons and high speed systems. (P. Barnes, AFRL/PRPS, (937) 255-2923)



Zirconium photo-electronic peaks of the YBCO superconductor as acquired by XPS

SUCCESS IN DEVELOPMENT OF POSS-STYRENES: Researchers in the Propulsion Directorate's Propulsion Materials Applications Branch (AFRL/PRSM) are investigating the development of POSS (polyhedral oligomeric silsesquioxanes) styrenes. Interest in POSS styrenes is fueled by their potential use as low dielectric materials for radomes. In the past, POSS-polystyrenes prepared by a solution process were of too low a molecular weight and were very brittle. Tougher polymers were needed to allow for dynamic mechanical and dielectric measurements. This limitation was recently overcome by the development of bulk polymerization methods of polymerizing POSS-styrenes. It was demonstrated that a 30 weight percent POSS-styrene copolymer could be pressed into films. A 0.04 inch (1 mm) thick, 1.25-inch diameter disk and a thin 4-inch diameter film were pressed and found to maintain excellent structural integrity. The parameters for pressing this material were 177°C for ten minutes under 1000 pounds per square inch of pressure. These are the same parameters normal

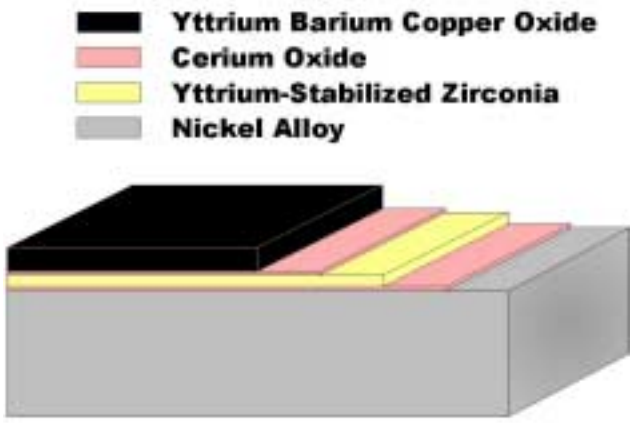
polystyrene requires for processing. (T. Haddad, AFRL/PRSM, (661) 275-5761 and P. Ruth, AFRL/PRSM, (661) 275-5799)

NAVY SUPPORT FOR AIR FORCE SUPERCONDUCTING PROGRAMS: On 4 January 2001, the US Navy invited representatives of the Propulsion Directorate's Power Systems Branch (AFRL/PRPS) to discuss its superconducting power efforts. In the discussions that followed, the Navy outlined an interest in high-power generators for powering the more electric ship, with multiple generators of 10-12 MW rating for this purpose. The Navy also asserted the importance of lightweight, compact power generation systems for naval vessels as well as improving energy efficiency to help improve fuel savings. The Air Force is currently seeking to develop the same high-power generators for airborne directed energy weapons in the 3-6 MW range. A resultant consensus from the meeting agreed that a joint high temperature superconductor (HTS) development program for a generator of approximately 8 MW power rating would provide proof of concept for both services. Representatives from DARPA were also present. Discussions are continuing with the Navy for YBCO (yttrium barium copper oxide) coated conductor development and power generation, and meetings are also being arranged with the US Army to determine if a similar system that is beneficial to Army needs can result in a tri-service program. (P. Barnes, AFRL/PRPS, (937) 255-2923)

Col Janiszewski, PR Director, congratulates Mr. Harootyan on his retirement

HAROOTYAN RETIRES FROM GOVERNMENT SERVICE: On 3 January 2001, Mr. Leo S. Harootyan Jr. retired from Government service. His retirement marked the end of a distinguished 37-year career as an engineer and supervisor within the Department of the Air Force. Of these 37 years of service, 27 were spent in the organization that is now the Propulsion Directorate. The remaining 10 years, spanning the period of 1980 to 1989, were spent on staff at the Air Force Wright Aeronautical Laboratory (AFWAL) and the Wright Research & Development Center (WRDC), organizations that would evolve into the present day AFRL. During his final 11 years of service, Mr. Harootyan was a division chief within the Propulsion Directorate. In this role, he was responsible for key fuel, lubrication, and combustion technologies. Among the many successful technologies developed or advanced during his tenure were JP-8+100 fuel, the trapped vortex combustor, vapor phase lubrication, magnetic bearings, and pulsed detonation engines. Mr. Harootyan was awarded the Outstanding Civilian Career Service Award in recognition of his many contributions in an award ceremony on 19 December 2000. (R. Hancock, AFRL/PRTS, (937) 255-7487)

TITLE III OFFICE SELECTS CONDUCTOR PROGRAM: The Defense Production Act Title III office has selected the YBCO (yttrium barium copper oxide) coated conductor research program as one of its top choices for consideration for Title III funding. This project will transition high temperature superconducting (HTS) YBCO coated conductor materials into production for use in both military and commercial systems. The resulting program will establish an economically viable production capacity that provides for domestic production of long YBCO-coated conductor (over 100 meters), with the necessary electrical properties for use in generators, motors, and magnets. Goals for the HTS YBCO coated conductor are: 1) $5 \times 10^5$ amps/cm$^2$ at 77 K critical current density, 2) 20,000 amps/cm$^2$ at 77 K engineering current density, 3) conductor lengths greater than 100 meters, and 4) cost of $15 per kA-m. The YBCO material is accepted world wide as a second generation HTS conductor, with several advantages over existing superconductors. Use at liquid nitrogen temperatures (77 K) results in a substantial weight and cost savings in cooling requirements compared to 4 K for low temperature superconductors and 30 K for first generation HTS conductors. YBCO is able to maintain current densities over $10^5$ A/cm$^2$ in multi-Tesla magnetic fields, whereas first generation HTS conductor begins to drop dramatically under 1 Tesla. Good pinning properties and substantial reduction in ac losses exist over the first generation HTS conductors which are over 50 percent silver--a more costly material compared to nickel alloys. But long lengths of YBCO-coated conductor are required to develop for application as coil windings in HTS generators as well as the HTS magnet windings. The YBCO-coated conductor can reduce the cost of the HTS wire from $300 per kA-m (current HTS BSCCO) to $10 per kA-m, a significant savings in addition to improved properties. The unique advantages of this conductor result in increased efficiency, compact size, and lighter weight for HTS generators and magnets that are needed for directed energy weapons and radio frequency source magnets for Air Force airborne applications. The YBCO-coated conductor is also a critical component for meeting the systems requirements of Navy superconducting motors and magnets (aircraft launch and mine sweeping operations) and Joint-Service non-lethal weapons applications. (P. Barnes, AFRL/PRPS, (937) 255-2923)



Coated conductor structure

AIRBORNE LASER SPO SUMMONS THE POWER: In December 2000, representatives of the Propulsion Directorate's Power Generation Branch (AFRL/PRPG) met with the Airborne Laser (ABL) SPO at the SPO's request. The meeting grew out of the SBIR topic selection process as the ABL SPO was looking for advanced power and cooling technologies to support the ABL EMD phase. Representatives of Air Combat Command (ACC) were also present at this meeting. The SPO representatives briefed their technical challenges for the full power EMD aircraft, and explained the differences from the PDRR aircraft that is scheduled for summer 2001 delivery to Edwards AFB for testing. Power Division (AFRL/PRP) representatives briefed on a few

technologies that may be able to increase the cooling capacity, decrease the thermal load, and put more electric power on board for air and ground use. The SPO expressed a great deal of interest and stated that the timing was right to think about advanced power technology application in the EMD phase. The ACC representatives have been added to the coordination that will investigate more details with the subsystem contractors after receiving the points of contact from the SPO. (C. S. Rubertus, AFRL/PRPG, (937) 255-6241)